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Solar Dryer with Pneumatic Conveyor

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Abstract

The coventional flat bed dryer has the demerit of having nonhomogeneous drying results. Therefore, to obtain nonhomogeneous drying result recirculating type solar dryer with pneumatic conveyor as the recirculating equipment will be. As the grains transported within the penumatic conveyor rapid heat and mass transfer occur resulting in even drying process and make the final results of the drying process homogene. The complete solar dryer was comprised of a feed hopper, centrifugal blower, pneumatic conveyor and a transparent structure acting as drying chamber containing a hopper with vortex at the top. Pneumatic conveyor was used to make recirculation of the grain and to perform continuous drying process. Spherical model was used to predict the drying time.Test with 104 kg of rough rice indicated that the drying time required to reduce the moisture content of rough rice from 28.4 % w.b to the final moisture of 14.3 % w.b was 5 h. During the test the drying temperature was kept constant at 50.1 ^{o}C and RH of 21.73 %. The required power for the pneumatic conveyor was 581 W with total energy input of 210.7 MJ including LPG and solar radiation. The resulting drying efficiency was 22.4 % with specific energy of 15.2 MJ $\cdot$ kg^{-1} water evaporated.

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Keywords: Drying efficiency; penumatic conveyor; specific energy; solar dryer.

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Nomenclature

Ac	surface area of hopper exposed to solar radiation (m^2)	**Subcript**	
Cp	specific heat ($kJ \cdot kg^{-1}$ ^oC)	**D**	drying
CV	calorific value ($kJ \cdot kg^{-1}$)	**E**	equillibrium
Dv	mass diffusivity ($m^2 \cdot s^{-1}$)	**G**	gas
ΔHfg	latent heat of vaporization ($kJ \cdot kg^{-1}$)	**H**	hopper
$\mathbf{I_{RAD}}$	solar radiation ($W \cdot m^{-2}$)	**i,**	intial
K	the drying constant ($1 \cdot h^{-1}$)	**f**	final
M	moisture content (% db)	**o**	initial
Pw	electric power (Watt)	**p**	rough rice
$\mathbf{S_E}$	Total specific energy ($kJ \cdot kg^{-1}$water evaporated)	**r**	recycling
T	time (h)		
W	mass (kg)		
X	moisture content (% wb)		

Greek letter

θ_R	recycling time
η_D	drying efficiency

1. Introduction

Most farmers in the developing countries still use the direct sun drying for the preservation of foods. This traditional method although cheap they are susceptible to dirt, foreign materials and are accessible to animals and require larger open space. As alternative to this traditional method many have suggested to use mechanical solar drying system in which temperature, relative humidity (RH) and air flow rate can be controlled to produce even and good quality of the final product. [1,2]. One of the conventional drying system is using a flat bed dryer where products are filled in a box and heated from below. Such a system has the demerit of making uneven final moisture content where the garins in the bottom layer prone to dry faster than grains in the top layer.

Therefore, we are proposing a continuous system using penumatic conveyor [5], where while being tarsported in turbulent manner, the grains are heated by the carrier hot air resulting in rapid mass and heat transfer process to occur. Such process will make the final moisture of the grains become homegene. In addition the drying process can be completed in a shorter time due to the turbulent manner of drying process which occur within the pneumatic conveyor. In the previous study [5] a recirculation type ICDC (Integrated Solar Collector Drying Chamber) solar dryer has been designed and costructed for the purpose of drying granular materials, namely rough rice. In the study a pneumatic conveying system was also used to recirculate the grains within the drying system.

1.1. The drying process

If the grain can be assumed as a spherical body, then the drying porcess can be expressed by the following relation [3].

$$\frac{\partial M}{dt} = D_v \{ \frac{\partial^2 M}{\partial r^2} + \frac{2}{r} . \frac{\partial M}{\partial r}) \tag{1}$$

Which can be solved under the following IC and BC.
IC : at t = 0, 0 < r < R, M = M (0)
BC : at t > 0, r = ± R, T = constant, RH = constant, M = Me
The solution of eq.(10) in a simplified form is given below [6], taking the first term only[4].

$$\frac{\overline{M}-M_e}{M_0-M_e}=A\exp(-Dv\pi^2 t/r^2) \tag{2}$$

Here A is the shape factor (-), r. is equivalent radius of the grains (m) and k is the drying constant 1. h^{-1}). Under turbulent drying process the value of k was found to be 1.25 ($1 \cdot h^{-1}$) and Me 6 % db. [5].
The amount of drying during each re-cycling process could be estimated from the re-cycling time θ_R, calculated from the known amount of grain remaining in the hopper,W_h and the re-cycling rate of the grain, W_R within the dryer, such that.

$$\theta_R=\frac{W_h}{W_R} \tag{3}$$

Where from previous study by Kamaruddin et al. [5] the value of W_R can be estimated using the following relation

$$W_R = 1.152Pw + 7.52 \tag{4}$$

1.2.The drying efficiency

The drying efficiency, η_D can be defined as the ratio between the useful energy to dry the grain with total energy input. Therefore

$$\eta_D=\frac{(m_{pf}Cp_fT_{pf}-m_{pi}Cp_iT_{pi})+\{\frac{(X_i-X_f)W}{(1-X_f)}\}\Delta H_{fg}}{Pw\,t_D+W_gCV_g+I_{rad}A_c} \tag{5}$$

The total specific energy, S_E is defined as the total energy input to amount of water vapor evaporated.

$$S_E=\frac{Pw\,t_D+W_gCV_g+I_{rad}A_c}{\{\frac{(X_i-X_f)W}{(1-X_f)}\}} \tag{6}$$

2. The experiment

Figures 1a and 1b show the experimental set up. It shows the main component of the solar dryer which comprised of a blower (1), a feed hopper (2), LPG stove (3), transparent structure (4), pneumatic conveyor (5) and a receiving hopper (6). The transparent structure will act as a solar heat collector as well as simultaneouly become the drying chamber. Before filling the hopper with the grains, temperature sensors (Type k thermocouples, Chromel-Alumel) were placed in a specific locations at the pneumatic conveyor inlet and out let, at the drying chamber, at the hopper wall, and at the inlet and out let of LPG stove. The RH meter (Lutron type BG-UT-02P) was placed within the drying chamber, while a digital pyranometer (Tenmarr Type TM 206) was place in horizontal position to measure global solar radiation. In addition a volt and ampere meter were used to measure the electricity consumption during the drying process. A Lutron type DW 6060 anemometer was used to measure air flow rate at the blower inlet. During the experiment rough rice was filled into the feed hopper to a certain amount while keeping the blower operating until the grains has been collected in the receiving hopper. During this operation the valve below the receiving hopper was closed. The hot air from LPG stove was supplied into the blower inlet, keeping valve below the feed hopper closed while valve below the receiving hopper open. In this way the grain will flow from the receiving hopper into the pneumatic conveyor and back into the transparent structure which also function as the drying chamber and finally fall into the receiving hopper and thus completing the recycling process. Such recicling process will continue untill the final mositure content of the grain was achieved.

Figure 1a. Blower (1), feed hopper (2), LPG stove (3), transparent structure (4), pneumatic conveyor (5), and receiving hopper (6).

Figure 1b. Vortex (7), receiving hopper (6) and pneumatic conveyor (4).

3. Results and discussion

Figure 2 shows the drying curve of under 104 kg load of rough rice. It took 5 h to dry from 28.4 % w.b to the final 14.3 % w.b. Figure 3 shows the drying air and hopper temperature. The Figure 3 shows that the drying air temperature almost constant at 50 ^{o}C, while the hopper temperature varies between 50 oC to 60 ^{o}C. Fig.4 shows the variation of solar radiation during the day in which was only available from 14:30 to 17:30 with the highest insolation at 590 W/m^2.Total gas consumption was 4.3 kg with total electricity consumed was 2.905 kWh or an average power consumed was at 580.9 W. The total solar radiation received was 8.724 kJ. Under this condition the drying air temperature was at 50 ^{o}C, and hopper temperature of 54.5 ^{o}C, with drying chamber RH at 21.73 %.

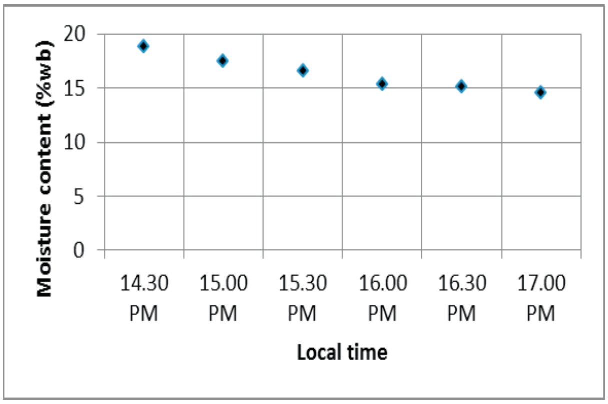

Figure 2. The drying curve of 104 kg load of rough rice

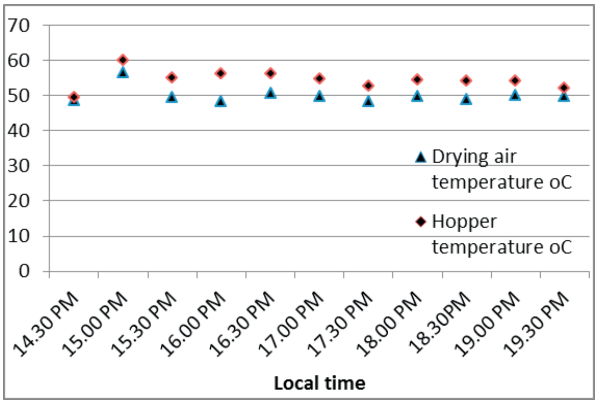

Figure 3. Variation in drying chamber and hopper temperature

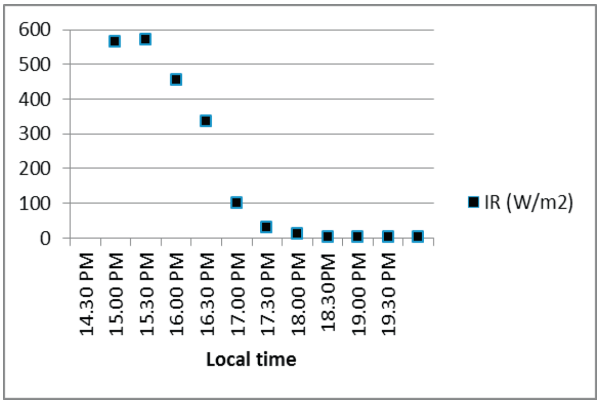

Figure 4. Variation of solar radiation during the experiment

3.1. *The drying efficiency*

The drying efficiency was calculated using Eq. (4) and was found to be 23.6 %, while the total specific energy calculated using Eq. (5) was found to be 14.6 MJ · kg^{-1} of water evaporated. Figure 5 shows the drying curve for the 200 kg load test. It took 8 h to dry from 27.3 % w.b of rough rice to the final moisture contant of 14.6 % w.b. The electricity consumption was 578.2 W on the average and the LPG consumption was 6 kg with total of 10.487 kJ of solar radiation. The average drying temperature was 47 ^{o}C.

Based on these data the calculated drying efficiency was 35.7 %, while the total specific energy (including solar energy input) was 9.475 MJ · kg^{-1} water evaporated. Figure 6 shows the comparison between the calculated drying curve using Eq. (2) and Eq. (3). It shows that the model used predicted quite well of data obtained. Here the value of parameter. The shape factor, A was given a value of unity larger than for the case of spherical body which is $6/\pi^2$.

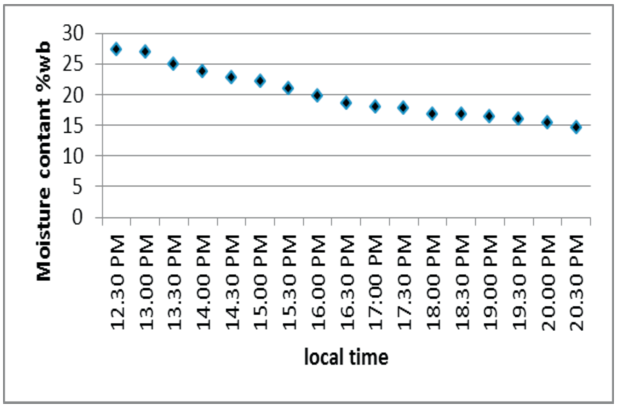

Figure 5. The drying curve for the 200 kg load test

3.2. *Comparison with theory*

Figure 6 shows the comparison between predicted drying curve using Eq. (2) with coefficient k = 2.5 (1 · h^{-1}) and Me = 6 % db.and Eq.(3) for the rate of recirculation. During the test the amount of rough rice within the hopper was 55 kg which indicated that the recirculation time of 0.8136 h · $cycle^{-1}$

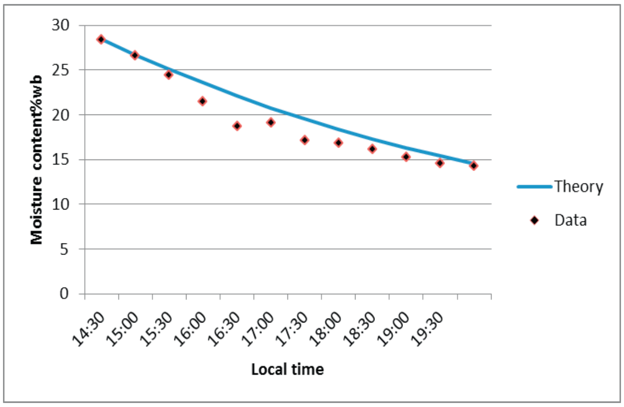

Figure 6. Comparison between theory and data for the 104 kg drying test

3.3. Homogenity in moisture content

As described in the earlier section that by using penumatic conveying system drying process will proceed in turbulent manner resulting in homogene final moisture content. A five sample each from each measuring time indicated that the variation in moisture content of the sample reduced as the drying process continuous toward the end (See Fig.7).. It varies from 2.9 % at the earlier stage of drying to 0.4 % at the final drying stage. These results have shown much lower than using flat bed dryer even with reverse air flow being applied Hien et al.[6].

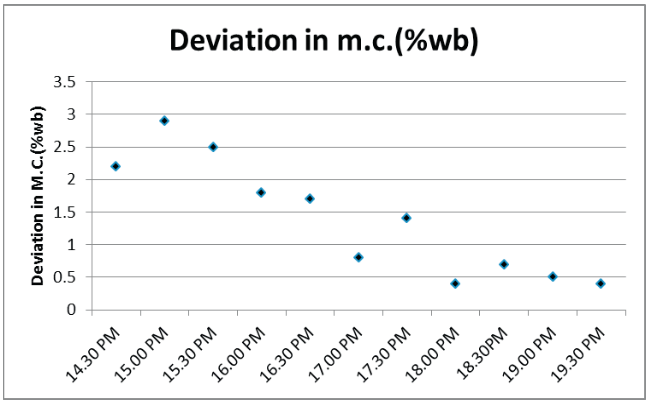

Figure 7. Deviation in moisture content % wb.

4. Conclusions

- With 104 kg load of rough rice the solar dryer was capable to reduce the initial moisture content from 28.4 % w.b to final moisture content of 14.3 % w.b within 5 h. The drying air temperature was 50 ^{o}C and the RH was 21.73 %. The electric power used was 580.9 W while the LPG consumed was 4.3 kg and solar radiation of 8.724 kJ.
- The drying efficiency of the dryer was 23.6 % while the total specific energy (including solar radiation) was 14.6 MJ $\cdot$ kg^{-1} of water evaporated.
- Under 200 kg load of rough rice the required drying time to reduce the initial moisture content of 27.3 % wb to 14.6 % wb was 8 h. The drying process was conducted under drying air temperature of 47 ^{o}C, where the electric power used was on the average of 578.2 W, the amount of LPG consumed was 6 kg, and solar radiation of 10.487 kJ.
- The drying efiiciency of the dryer was 35.7 % while the total specific energy (including solar radiation) was 9.475 MJ $\cdot$ kg^{-1} of water evaporated.
- Comparing the predicted drying curve and data it shows that all da ta have a lower value, although the deviation is small.
- The variation in moisture content during the drying process was smaller that that using flat bed drying varying from 0.4 % to 2.9 % w.b.

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